

Continuous-wave operation of quantum cascade laser emitting near 5.6 μm

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Buried heterostructure quantum cascade lasers emitting at 5.64 μm are presented. Continuous-wave (CW) operation has been achieved at -30°C for junction down mounted devices with both facets coated. A 750 μm -long laser exhibited 3 mW of CW power with a threshold current density of 5.4 kA/cm^2 .

The spectral region near 5 μm is of great interest for various applications such as absorption spectroscopy, countermeasures or telecommunications. Quantum cascade lasers (QCL), now covering the spectral range between 3.4–16 μm , are the only semiconductor lasers that can operate at room temperature within this spectral region [1, 2]. But up to this point, continuous-wave (CW) operation at room temperature was only achieved for QCLs emitting at 9.1 μm [3]. CW operation was possible by using the buried heterostructure (BH) technology that improves heat dissipation and reduces lateral waveguide losses. High-performance QCLs emitting at 5–6 μm and operating above room temperature were reported in [4–6], but only in the pulsed regime.

In this Letter, we report a strain-compensated, buried heterostructure QC laser based on a four quantum well (QW) active region emitting at $\lambda = 5.64 \mu\text{m}$. The waveguide consists of an n -doped InP substrate, a lower InGaAs guide layer followed by the laser core with the active laser region, an upper InGaAs guide layer, an InP top cladding with lower 2.5 μm -thick and upper 0.85 μm -thick InP layers (doped to $n = 1 \times 10^{17} \text{cm}^{-3}$ and $7 \times 10^{18} \text{cm}^{-3}$, respectively), and a highly doped ($n \sim 2 \times 10^{19} \text{cm}^{-3}$) InGaAs contact layer. The guide layers and laser core were grown by molecular beam epitaxy (MBE) whereas the InP top cladding and the top contact layer were grown by metal organic vapour phase epitaxy (MOVPE). Both 300 nm-thick $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ waveguide layers are doped to $n = 6 \times 10^{16} \text{cm}^{-3}$ and grown lattice matched to the InP substrate. The strain-compensated active region, described in detail in [6], consisted of 28 periods.

After growth, lasers are wet etched as 12 μm wide and 5 μm deep mesa ridge waveguides using an SiO_2 mask which prevents InP deposition on top of the laser cladding layers during the following MOVPE regrowth of 5 μm of non-intentionally doped InP. The SiO_2 film is removed chemically after the lateral regrowth step and nonalloyed Ti/Au ohmic contacts are finally evaporated to the top of the highly doped cladding layer. Laser fabrication is finished by substrate thinning and evaporation of alloyed Ge/Au/Ag/Au back contacts.

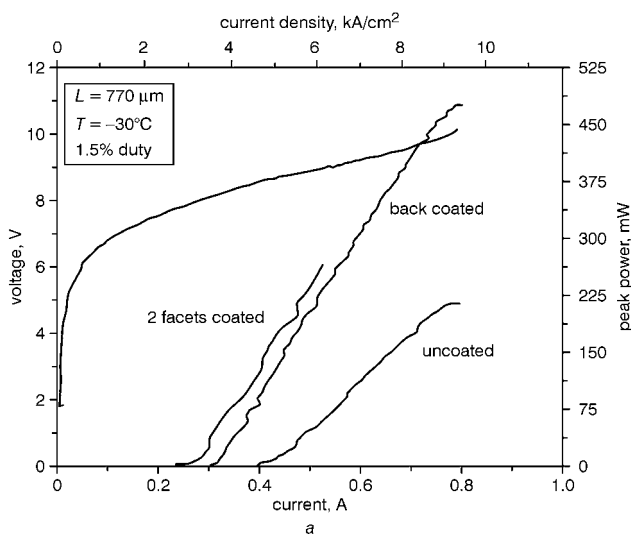


Fig. 1 L - I - V curves of same 770 μm -long junction up mounted QCL with three cavity configurations

The device was tested at a low duty cycle (1.5%) with 150 ns-long pulses. Optical power was measured with a thermopile powermeter.

The L - I - V characteristic of a 770 μm -long junction up mounted device is shown in Fig. 1 for three cavity configurations: as cleaved, with a high-reflectivity (HR) coated back facet ($\text{Al}_2\text{O}_3/\text{Au}/\text{Al}_2\text{O}_3$ 300/100/100 nm, $R \approx 97\%$) and HR/HR coating, where the front coating consists of a single 250 nm PbTe layer, providing $\sim 65\%$ of reflectivity. The threshold current densities at -30°C for these configurations were 4.8, 3.7 and 3.3 kA/cm^2 , respectively. The maximum peak power for the uncoated and back facet coated devices reached 215 and 465 mW, respectively. The respective slope efficiencies dP/dI were 640 and 1050 mW/A for these two configurations. For the device with both coated facets the power measurements were stopped before thermal roll-over due to the risk of a heat-induced destruction of the front coating. At 24°C the uncoated device exhibited 6.5 kA/cm^2 of threshold current density and 95 mW of maximal peak power ($dP/dI = 485 \text{mW}/\text{A}$). The deduced characteristic temperature T_0 of the device was 165 K.

The devices were then tested at high duty cycle. A pulse length of 150 ns was used with a variable pulse repetition frequency, starting from 100 kHz (duty cycle 1.5%). Fig. 2 shows the evaluation of the maximal average optical power with the duty cycle for the same device with uncoated facets and with a coated back facet. The highest average power was attained at 25% duty cycle for the uncoated sample at -30°C and it reached 30 mW/facet . For the device with the coated back facet the maximal average power was attained at 30% and was 80 mW. At 24°C the uncoated device exhibited the highest average power at 12% of duty cycle and it reached 7 mW/facet .

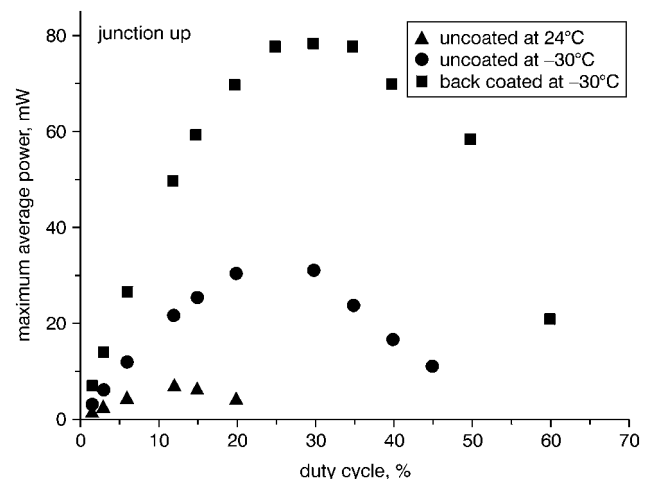


Fig. 2 Thermal roll-over maximum average power against duty cycle of 770 μm -long junction up mounted device

Afterwards, a 750 μm -long device was mounted epi-side down directly on the copper heatsink with tin-lead alloy, then both its facets were coated and it was placed onto a Peltier cell. Fig. 3a shows L - I - V curves measured in the CW regime at -30°C . To protect the device from catastrophic failure, the measurement was stopped just after having reached the threshold. The threshold current density was 5.4 kA/cm^2 with a maximal output power of 3 mW and a slope efficiency of 90 mW/A . Fig. 3b shows a CW spectrum collected with a NICOLET 800 FTIR spectrometer just above threshold.

Conclusion: We have demonstrated a buried heterostructure quantum cascade laser emitting at 5.64 μm . The laser with coated facets operated at continuous wave regime at -30°C with a threshold current density of 5.4 kA/cm^2 and delivered 3 mW CW power. CW operation was achieved thanks to BH technology and junction-down mounting, which improved the heat dissipation, and by using high-reflectivity coating of both laser facets, thereby decreasing significantly the threshold current density.

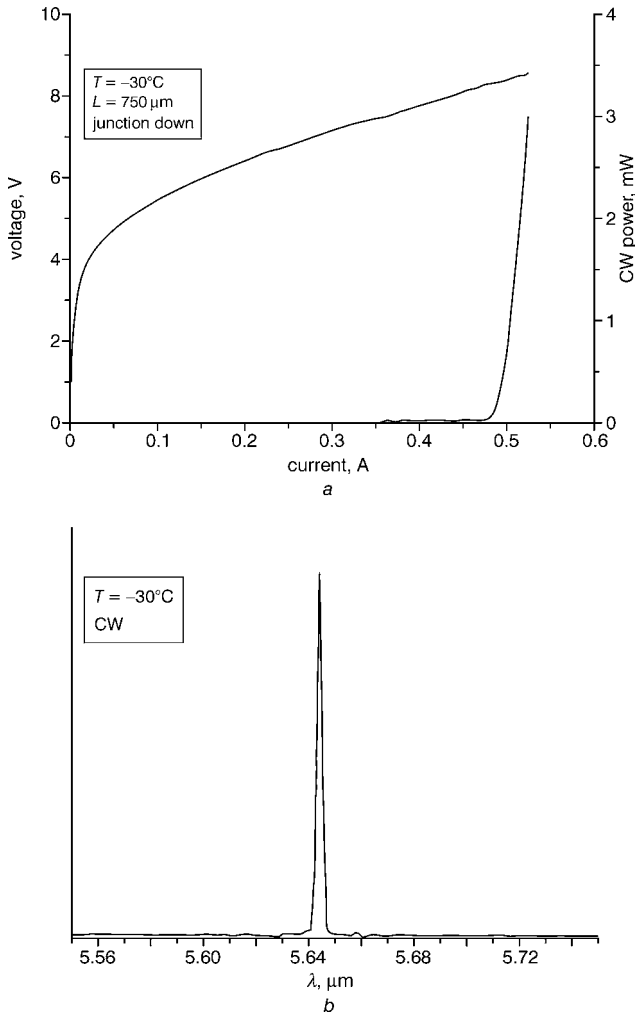


Fig. 3 CW L - I - V curves and CW spectra of QCL

a CW L - I - V curves of 750 μm -long junction down mounted QCL at -30°C
b CW spectra of QCL at -30°C
 Emission wavelength is 5.64 μm

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